VOLUME XXXVIII NUMBER 1 WHOLE NUMBER 330

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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PUBLISHED MONTHLY
(*Ten numbers per year*)

January, 1944

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL

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Address of Editors: David Dunlap Observatory, Richmond Hill, Ont.

Business correspondence, remittances, etc., should be addressed to J. H. Horning, Treasurer of the Society, 198 College Street, Toronto 2B, Ontario.

$2.00 per annum. Single numbers, 25 cents.

Subscription to the JOURNAL is included in membership fee.

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PRINTED IN CANADA

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WHAT IS A ROCKBURST?

By ERNEST A. HODGSON

The following is the text of the twelfth in the series of educational and informative talks presented over radio station CJKL by the mine managers of Kirkland Lake and district. The nature of the talk, which was given September 7th, 1943, and the name of the speaker are contained in the introductory remarks of the announcer which follow:

"The speaker tonight in the twelfth in the current series of educational talks sponsored by the mines of Kirkland Lake and Larder Lake is Dr. Ernest A. Hodgson whose subject will be 'What is a Rockburst?'. Dr. Hodgson, for the last thirty years, has been seismologist at the Dominion Observatory at Ottawa. For the past five years, the rockburst problem has been his major interest. The Dominion Government, through the Department of Mines and Resources, is interested in rockburst research work and has loaned the services of Dr. Hodgson to Lake Shore Mines, Ltd. The problem of rockbursts dates back to early history of mining and has, for years, been a difficult problem in widely scattered parts of the globe such as India and South Africa. Lake Shore Mines, primary interest in the subject is the safety of their underground men. The Ontario Mining Association, through its special committee on rockbursts is doing a great deal to assist in this research work. From the work of Dr. Hodgson and his staff, it is hoped that instruments will be developed which will give ample warning of impending rockbursts. This talk will, therefore, be of particular interest and it is with pleasure that I now introduce Dr. Hodgson."

Dr. Hodgson:

"Quiz programmes did not originate with the radio, and hundred dollar questions are pikers compared with the prizes given for correct answers to those proposed by Mother Nature. One of her million dollar questions is 'What is a Rockburst?'. But, she doesn't accept guesses and half answers. To get the prize you must give the complete and correct definition.

"Those in mining districts might claim to be able to answer this question. They know that, when a rockburst occurs in a mine, there is a sudden concussion which can be felt even on the surface and, in some cases, for several miles. The miners themselves know that, in the vicinity of the burst, timbers are crushed like match sticks, that rock flies from the face of the underground openings affected and that whole sections of the mine may have these openings more or less completely closed by debris. They know that the rock bursts upward from the floor quite as often as it bursts in from the sides or down from the roof of a tunnel or drift. They know that these bursts are often preceded by periods when the walls are said to 'talk' in and around the danger zone. That is, the solid rock snaps from time to time, the timbers crack and squeeze and, sometimes, small pieces of rock fly off from the exposed face of the stone. They know, too, that this 'talk' quite often disappears for some days before a burst but that *the stope does not always burst after the walls become quiet.*

"Mining engineers know that rockbursts can be controlled to some extent by the methods and order of mining and by the speed with which the work is done. They know that rockburst hazards may be reduced by timbering the mined-out sections and filling the openings with sand and rock or other 'back-fill.'

"But the million dollar pay-off comes only for the complete answer. Nature demands that we know why some rocks burst and others at equal depth do not; what force causes them to burst; is there any means of determining whether a stope which has stopped 'talking' is freed of pressure or is going to burst. These and many other parts are included in the whole simple question, 'What is a Rockburst?', and Nature will not be satisfied to award the prize for less than the complete answer.

"For the past five years, Lake Shore Mines has been devoting much time and expense to a special study of rockbursts, hoping to come near enough to the answer to win, at least, a partial award. It takes time and money and patience. I can, in this short talk, indicate only a little of the programme now being carried out.

"Suppose we had a great many blocks of good solid Lake Shore rock, cut into cubes a foot on a side. Suppose we were to put one of

these down on a flat solid surface and then pile the others, one after another, on top of it. How high could we pile the blocks before the bottom one would burst? We assume, of course, that the blocks are all of equal strength.

"To answer this question, a little more simply, we took several samples of rock from the mine to Ottawa, where they were sawed into blocks about six inches cube and these blocks were carefully polished to a smooth surface. Then, one by one, each was put into an hydraulic press capable of exerting as much as 200 tons pressure and was there slowly squeezed until it burst.

"Let us follow the history of what was actually one of these tests. We are watching the oil pump slowly building up pressure on the little cube of rock. Once in awhile, as the pressure gauge goes higher, we can hear faint sharp snaps. Suddenly there is a much heavier snap. The gauge shows that the rock is now under the same pressure as if we had piled 8,360 of those foot cubes of which we spoke awhile ago. We remove the sample and find that, while it is checked a bit, it still seems quite solid.

"So we put it back in the press and find that, when we get as much pressure as before, it seems quite able to take it. The pump goes on putting in more oil. From time to time the tiny snaps occur as before. Then, suddenly, there is another large snap. The pressure is now as great as if we had piled 15,000 blocks on the bottom one. But, again, the sample, when removed from the press, seems solid.

"It is put back again and goes on taking pressure. When the gauge shows that it is under more than the equivalent of 20,000 blocks, there is a violent heavy concussion which can be heard and felt over the entire building and out into the street. We have had a rockburst,—but only a six-inch cube, not an entire stope. Let us consider this experiment.

"The sample burst when subjected to pressure equal to 20,000 feet of overlying rock. But the rocks burst in a mine at depths much less than that,—from 1,000 feet down or so. However, if, instead of piling our 20,000 blocks one on top of another, we had put down a single one for the first layer, then two side by side, each covering half of the bottom block, for a second layer, three for the third layer, four for the fourth, and so on, then this upside-down pyramid of

20,000 blocks would have been only 200 feet high. All would, as before, have been resting on the single bottom block.

"Now the rocks in a mine are not one single volume, but are jointed into pyramid-like blocks. And the mining takes out part of the support and leaves smaller and smaller sections to hold up large overhanging volumes. It is for these reasons that the rocks burst at depths less than 20,000 feet. But they do not burst until they are subjected to pressures as great as this. Indeed, since they are always partly surrounded, they will take even higher pressures without bursting. The pressure on a straight pile 20,000 feet high amounts to about 26,000 lbs. per square inch. The rocks at Lake Shore will stand that much pressure and more before they burst. Then, because they are brittle, they do burst. Other rocks, such as those at some other camps, actually flow very slowly under pressure, something like the way a wax candle slowly bends out of shape in a warm room. When rocks flow in this way there is much less danger of rock bursts even at considerable depths.

"In the pressure experiment, the specimen snapped sharply at pressures much less than that at which it burst. It was afterwards quite strong, for it went on taking pressures higher and higher. It is probably snaps such as this that make up at least part of the wall 'talk' heard in the stopes taking pressure.

"When the sample finally burst in the press, there was a very heavy concussion, but no windows were broken in the laboratory, and no damage was done to the press or other equipment. Rock does not compress very much. The jaws of the press had only to spring back a small fraction of an inch to bring the pressure in the press to normal. It was quite different from an explosion where the force is produced by the generation of enormous quantities of gas, as in a dynamite blast.

"Contrary to general belief, there is no generation of air when a rockburst occurs. The flying rock fills up certain openings underground and the air so displaced rushes out by way of the drifts, but there is no more gas or air there than before—none is generated by the burst. The concussion is carried by the rock, not by the air, and only in a few special cases does the flow of displaced air from the burst cause any damage.

"Again, you remember that the sample snapped faintly with tiny, high-pitched snaps, in addition to the heavier snaps which halted the experiment until the sample could be examined. It was long suspected that, if one could use suitable pick-up and amplifying equipment, it might be possible to hear many of these tiny snaps and others which would otherwise be too faint to be noticed. It was believed, too, that, contrary to the behaviour of the 'talking' snaps, these small ones might become more numerous before the rock collapsed.

"Lake Shore Mines now has equipment for doing just this type of listening. And it is found that the tiny snaps *do increase in number* as the pressure goes up. They stay close to the place where the pressure point is and cannot be heard more than a hundred feet at most from that point. Experience shows that dangerous pressures build up within a few hours and that they go away in as short a time, to be taken up by some other nearby section.

"It is evident that we have here a means of locating pressure points and of knowing when the pressures come and when they go. If we have many listening points we can follow their movements and their magnitudes from day to day by means of the average number of snaps per minute registered on the listening equipment. Experience alone will enable us to learn where best to put the pick-up devices and how to interpret their records. But it is believed that we have, in this method, a means to enable us, day by day, to come ever nearer to the prize-winning answer to the million dollar question of Nature—'What is a Rockburst?'."

At the end of his talk Dr. Hodgson was asked why he referred to the rockburst problem as a "million dollar question." He replied as follows:

"Of course the word *million* was just a large, round figure to compare with a hundred when I spoke of the hundred dollar question of a quiz programme. As a matter of fact, one cannot estimate the value of a device such as we are trying to perfect, which will protect men working underground from the menace of rockbursts. It is hoped that we may be able to develop the present method to the point where we can *know* that a stope is safe from rockbursts before the men go on shift.

"It will take time to accomplish this, but we are working patiently to that end and the method gives great promise. Lake Shore has spared no expense to secure this protection. During the past four years to date, they have already spent more than $70,000 on this work alone and they propose to continue such expenditures until the protection is assured. And, if the method is perfected here, it can be used in other deep, hard-rock mines where rockbursts occur, in Canada, the United States, South Africa, India, and elsewhere. The word *million* is surely an understatement, but one cannot set down any figure as the value of such protection.

"Let me emphasize that Lake Shore Mines is primarily interested in the safety of their men. This method of prediction does not prevent the financial losses which are involved in rockbursts. Their prevention is the business of the mining engineer."

Dominion Observatory,
Ottawa, Ontario.

THE EFFECT OF THE DISCOVERY OF THE BAROMETER ON CONTEMPORARY THOUGHT*

By G. S. Brett

THE significance of an important discovery in any field of knowledge may be considered in two distinct ways. The fact or principle which is discovered becomes an addition to science as a body of technical knowledge: it may also have a wider significance in so far as it is influential in changing opinions which are fundamental to the concepts of Nature and the method of natural science. The discovery of the barometer is a good illustration of this twofold aspect of progress. It provided an instrument for scientific measurement of atmospheric conditions and, in addition to that, contributed an important factor in the growth of a new attitude toward the world of human experience. Taken by itself the discovery of the barometer appears to be a rather isolated event, concerned with a very limited problem and resulting in the production of one more instrument to record what Eddington calls "pointer readings." Taken in a wider context it becomes a crucial test of ideas and traditions which were woven equally into the natural science, the cosmology and the theology of the later middle ages and the renaissance. In this commemoration of the actual discovery as an event in the year 1643, it is proper to consider what relation it had to the larger area of thought in that period of transition.

The mediaeval interpretation of nature was dependent to a large extent on the Aristotelian doctrine, and it is the common practice of historians to describe the changes which constitute the rise of modern science as essentially the overthrow of that Aristotelian tradition. The usefulness of this formula has tended to obscure the fact that it is neither very accurate nor entirely adequate. In the nineteen hundred years which elapsed between the time of Aristotle and the days of Galileo the ideas of the Greek philosopher had undergone subtle changes: the combination of Greek naturalism and Christian supernaturalism gave new meanings to old concepts and produced a conflict

*A paper read at the Tercentenary Commemoration of the invention of the Barometer, at Toronto, October 19, 1943.

of opinions which was in many cases based on errors of interpretation. One of the most significant examples of this distorted perspective was the doctrine of final causes. In the Aristotelian scheme the final cause is a principle of interpretation: it denotes the end of a process and affirms the necessity of considering the ultimate result as part of the explanation of process. The famous and much abused statement, that Nature does nothing in vain, is a valid rule of enquiry—namely, that every event has significance and every structure has a function. Greek thinkers were always interested in process, becoming, or genesis: they were accused by later generations of failure to teach a doctrine of creation. But if creation was not a part of the Greek concept of nature, neither were those ideas of destiny or fixed purpose which ultimately took precedence as the purposes of God, and were then discarded as having no place in the scientific study of nature. In this and some other similar cases the real conflict was between the more primitive or common sense ideas which had become firmly established and the more adequate theories which emerged with increase of information or improvement of instruments. The progress of science involves contradicting the primary data of sense-experience: the Copernican hypothesis could be denounced as contrary to the evidence of the senses: the idea that light moves was a product of astronomical study, not mere vision: it seemed obvious to the plain man that fire was a substance which escaped from the things in combustion.

The temptation to expand this theme must be resisted. It is relevant to our present subject because nothing is more obvious or apparently more simple than air. In some prehistoric age common sense devised a classification of nature into four basic types: earth, water, air, fire. Though commonly called elements, in historical times they were never truly elements but they were the persistent forms of matter. The distinction between them was qualitative, based on the way they seemed to behave and the effects they produced on the senses. They had their natural places: the evidence for this was drawn from observation of the deposits of soil, the condensation of moisture, the buoyancy of air and the leaping up of flames. The motion of a terrestrial body was either "violent," imparted to it by some other moving body, or "natural," because it tended always to return to

its own place. Air was "naturally" light in the sense that its natural place is above earth and water: in relation to the world air always tends to rise and therefore, relatively, it seems to have no weight. Thus we arrive at one of the most persistent traditions of early science: air has no weight.

The fact that air really exists and is not equivalent to empty space was demonstrated before 440 B.C. by Empedocles. He describes what happens when "a girl playing with a water-clock of shining brass, puts the orifice of the pipe upon her comely hand and dips the water-clock into the yielding mass of silvery water." The waterclock being a vessel open at both ends, Empedocles explains that the water cannot enter so long as the air is not allowed to escape, and conversely the water in the vessel will not flow out if the air is not allowed to enter at the other aperture. Aristotle reproduced this description of the effect of the pressure of air, but the experiment seems to have been regarded as a curious fact which did not lead to any further study of the subject.

The study of motion led the Greeks to conceive the idea of the void or absolute vacuum. The argument was purely logical. If a body was to move, there must be an unoccupied space into which it could move; or, conversely, when it moved the space which it left must become empty. With equally good logic it was possible to argue that if the void is truly nothing it cannot exist: it is not possible to think that bodies are separated by what is itself nothing. There is therefore no void but space is everywhere full, a plenum, and motion occurs by displacement without the necessity of a void. The atomists felt obliged to assert that the void existed, since otherwise the motion of the atoms would be impossible. Aristotle discussed the various arguments current in his time, such as the question of what happens when the volume of matter is reduced, that is, when rarefied matter becomes dense: does the contraction produce a void? He decided that there never is an actual void, but matter may go on becoming more rarefied without any known limit.

From this brief account of the progress of Greek thought it is possible to derive an idea of the relevant parts of the tradition called Aristotelian. Air was recognized as a distinct kind of material: it was capable of filling space and resisting the movement of bodies: it did

not exert pressure because it had no weight. The Universe was full: there was no void: but the matter which occupied all space might either be as dense as earth, or as rarefied as air and fire. As there is no unfilled space or void it may be assumed that in general Nature abhors a vacuum.

The recovery of the works of Aristotle and their translation into Latin provided a basis from which the study of nature began to develop after the thirteenth century. It was supplemented by other sources, more especially the great scientists of the Alexandrian age, such as Aristarchus, Archimedes, Euclid and Ptolemy. Because Aristotle far surpassed any other individual writer in the encyclopaedic range of his work, he took precedence over the others: his contributions to logic, ethics and politics were without a rival, and the supremacy which was supported by these works sufficed to give to his other works an importance which they did not equally deserve. This fact was not recognized by those who, as they claimed, took Nature for their book. In mathematics and physics Aristotle was judged deficient. To emphasize their emancipation from the Aristotelian schools the men of the Renaissance proclaimed their allegiance to the principles of the atomists whose reputation as atheists had for centuries obscured their merits in the field of natural science. By enlisting under the banner of the Atomists, the scientists hoped to escape from the cramping influence of an outlook dominated by concepts of fate, providence, and final causes. Though it is evident that the emancipation was far from complete, there was a steady growth in the direction of a new method and a new conception of the aims of natural science. More important than the spectacular crises of the conflict between orthodoxy and heresy was the tendency to concentrate on specific problems and develop appropriate methods of enquiry. Progress in mathematics and geometry increased the value of those instruments of science: calculation and measurement became the dominant factors in the description of natural phenomena. The qualitative terms which served to classify events as better or worse, natural or contrary to nature, gave place to precise formulae. Finally, the world, so far as science took account of it, became a mechanism in which matter, motion, force were the ultimate factors and the laws of nature were the formulae which expressed the various relations of these factors. To

establish these formulae, observation and experiment were needed, and some bold hypotheses which could stand the test of such verification as was possible: but the support of religion and the sanction of authority, whether biblical or Aristotelian, were definitely made unnecessary.

The changes here described belong to the period between the tentative suggestions of Roger Bacon and the great achievements of Galileo. The mention of Galileo calls attention to two points of immediate importance for our subject. Galileo died in 1642, one year before his pupil Torricelli carried out the experiment from which the barometer was derived. Also the problem which this experiment was designed to solve had been known to Galileo, for according to the accepted story he had been asked to explain why the pumps used to raise water from a well failed to act above an elevation of thirty three feet. Galileo was not prepared to explain this peculiarity. It is instructive to notice here the overlapping of old and new ideas. If the pumps were efficient enough to create a vacuum and nature abhors a vacuum, clearly the water should have done what nature desired. Galileo did more than any other man of his day to eliminate from physics such animistic factors as desire and the use of those final causes which operated by virtue of being desired ends. But in this case he could only compromise and suggest that nature's abhorrence of a vacuum ceased inexplicably at a height of thirty-three feet. That Galileo was not deeply interested in questions concerning the air seems indicated by the fact that when he invented a thermometer he did not recognize the possibility of measuring atmospheric variations. So it was left to Torricelli to take the final step.

The recognition accorded to Torricelli and to the importance of his demonstration was due primarily to the action of Mersenne. This indefatigable promoter of science did great service to the cause by his habit of communicating with a number of people to whom he made reports on all things worthy of note—performing a function of great value when scientific journals were almost unknown. Mersenne carried the news to France and the experiment was repeated in the presence of Etienne Pascal and his son Blaise. The son, henceforth referred to as Pascal, grasped the implications of the experiment. Two questions were involved. The question whether the air has

weight was considered to be answered in the affirmative: the reason why the mercury did not run out of the tube when inverted was also the reason why water stood at a corresponding height: the resulting equilibrium was due to the pressure of the atmosphere. The second question which then came to the front was concerning the state of the tube in the space above the mercury. If the tube contained nothing but mercury and the mercury fell a certain distance, the result must be the creation of a void. The belief that nature abhors a vacuum was open to two interpretations; either that there was no such thing as a vacuum because nature did not permit it, or that a vacuum must exist since otherwise nature could not abhor it! The first interpretation is the only one which deserves serious consideration. For Pascal and his contemporaries the subject was more complex than it appears to be at first sight.

The modern reader needs to be reminded that the word vacuum or void must be understood in its original significance as meaning complete nothingness, pure Non-Being. Torricelli, we are told, undertook his experiment to determine the limit of action of the vacuum. At the level of common experience there was quite sufficient evidence to support the idea that nature did not tolerate emptiness: the pump and the siphon were common instances. The error of explanation was in attributing to the vacuum a force of pull or attraction when the actual force in operation was the push of the air. But in addition to this primitive idea of the void there was the metaphysical question as to whether the existence of unfilled space was compatible with the right conception of God's omnipotence and omnipresence. It was considered contrary to good sense and piety that God should not have filled all space with created things. Giordano Bruno asks "Why should or how can we suppose the divine potency to be idle? Why should we say that the divine goodness, which is capable of communicating itself to an infinity of things and of pouring itself forth without limit, is niggardly?" Bruno bases his argument for the fulness of space on his pantheistic creed. Leibniz adopted a similar attitude but reinforced it by a direct appeal to the law of continuity. "Within this world no gaps of any sort could be admitted; Leibniz had a *horror vacui* which he was certain that nature shared. In its internal structure the universe is a plenum." If matter exists it must be continuous: there can

be no empty spaces in which God might have put material forms but failed to do so. The vacuists therefore are denounced on both grounds: they are wrong in their theology and deficient in their understanding of the law of universal continuity. In addition to this there was also the question of the material instrument by which the power of God initiated and transmitted motion, for if there was anywhere a vacuum there must also be action at a distance, in other words action transmitted by nothing.

When Pascal first repeated the experiment of Torricelli he apparently had not heard of the explanation which Torricelli gave. He believed that the mercury in falling created what he cautiously described as "an apparent void": the question uppermost in his mind was the possibility of determining the significance of this apparent void. His view that the upper part of the tube was probably empty brought him into conflict with Descartes who maintained that matter and extension are identical, and consequently that the apparently empty part of the tube must be filled with a "subtle matter." Pascal derided this notion of the existence of a kind of matter which was wholly imperceptible. Though Descartes had no experimental proof of his doctrine, he based it on two good arguments. He held, first, that if nothing at all was present in the tube, the sides would collapse: and also, in general, that if such a vacuum existed in nature, it implied "action at a distance." According to the mechanistic views which were steadily gaining recognition, all action was due to motion imparted by one body to another and these bodies must be in contact. There seems to have been some bitterness of feeling between Pascal and Descartes, which caused Pascal to treat the Cartesian physics with unmerited contempt. For this animosity there were two probable reasons. Pascal resented the claim which Descartes made that he was the real originator of the experiment to test the variation of the weight of air at different altitudes. Also Pascal was exasperated by the dispute with Père Noël, a former teacher of Descartes. Noël was primarily a supporter of the current Aristotelian philosophy, mixed with some ideas belonging to the Cartesian physics. Noël undertook to contradict Pascal's assertion of the void by arguing first that it was opposed to the teaching of Aristotle, secondly that it was contrary to true religion, and thirdly that the space in the tube was filled with a

subtle matter or pure air which was extracted from the gross air by the force of the descending mercury. Noël was not impervious to argument: he ultimately accepted the view that pressure of the air accounted for the position of the mercury, but he clung to his belief that the apparent void was full of something. Since this substance was admitted to have no function and could not be demonstrated, it was a good example of the defects of the old school. The historical importance of the dispute lies in the fact that it drew from Pascal a luminous statement of the true method of science. He stated that a hypothesis should lead to some possible verification, whereas Noël was merely making unverifiable assertions to support preconceived ideas: the apparently convincing argument of Noël that there was subtle matter in the tube because light was transmitted was dismissed by Pascal on the ground that no one knew the nature of light or anything about its propagation with or without a void. The support which Noël might get today from modern views of matter is not relevant to this dispute: Pascal was right in his position that assertions about physical phenomena must have meaning in physical terms: the right form of a physical hypothesis is "if this is x, it will act in a certain way under certain conditions," where the conditions are subject to observation. All Pascal's experiments conformed to this rule. They also contributed to another important conception, namely that scientific explanation is systematic: an isolated event is precarious: as the area of explanation increases the probability of being wrong decreases: there might be no final disproof of a subtle matter or even of the *horror vacui,* but there might also be no reason for keeping such factors when better explanations were available. A survey of Pascal's work shows that the original ideas were all known to others: his special contribution was his keen insight into the principles of method and proof which were involved and his capacity to move forward to wider generalizations. This was shown by the way in which he made an immediate transition from experiments with the Torricellian tube to the whole subject of his later works, namely the equilibrium of liquids in general and the significance of the weight of the air for predicting atmospheric conditions and determining altitude.

The significance of Pascal's work is attested by the enthusiasm which it aroused among those contemporaries who were capable of

appreciating its value. From Galileo through Torricelli and Pascal the way of progress leads to Robert Boyle. The spectacular methods of Guericke had emphasized the importance of the weight of air and his use of the air-pump showed the possibility of making a vacuum in the new mechanical sense equivalent to the reduction of pressure in a closed vessel. Through the publication in 1657 of a book entitled Mechanica hydraulico-pneumatica by Gaspar Schott he became acquainted with the work of Guericke and the uses of the air-pump. Boyle proceeded to improve this instrument and carry out experiments involving different degrees of pressure greater and less than that of the atmosphere. It was significant of the increasing tendency toward precise quantitative methods that Boyle was not content with the general principle already proved by Galileo, that air has weight: he devised a means of measuring the weight. By placing a barometer tube in the receiver of his air-pump he demonstrated in the laboratory what Pascal had proved in the mountains of Auvergne. The gentle irony of his comment on this experiment deserves quotation: "And as for the care of the public good of the universe ascribed to dead and stupid bodies, we shall only demand why, upon the exsuction of the ambient air, the water deserted the upper half of the glass tube, and did not ascend to fill it up until the air was let in upon it. Whereas, by its easy and sudden rejoining that upper part of the tube, it appeared both that there was then much space devoid of air and that the water might, with small or no resistance, have ascended into it, if it could have done so without the expulsion of the re-admitted air, which it seems was necessary to mind the water of its former neglected duty to the universe."

The air of our common experience approximates so nearly to an invisible substance that physicists were led to use analogies in their description of its action. Descartes used the analogy of wool, which appears also in the writings of Pascal. The mass of air was likened to a pile of wool, each part being a tiny coil which could be compressed: as the air extended to a great height, the upper portion pressed upon the lower portion and caused it to be more dense. Boyle's analogy was identical in principle: he used the phrase "the Spring of the Air" and thus gave a picture of the air as composed of particles each of which behaved like a spring, being compressed by

pressure and reacting against pressure. Boyle goes to considerable trouble to elaborate this parallel. As he progressed with his study of air he became more conscious (we may assume) of the difficulties introduced by the atomic or corpuscular doctrine. This had assisted the exponents of the new methods by providing a basis for their ideal of purely mechanical explanation. But as the field of study expanded its limitations became obvious. On account of the way in which air was subject to expansion and contraction, the atomic theory as then understood was not fitted to explain its characteristics. In 1662 Boyle wrote as follows: "Let us suppose the particles of bodies, at least those of air, to be of the form of a piece of ribbon, that is to be very long, slender, thin and flexible laminae, coiled or wound up together as a cable, piece of ribbon, spring of a watch, hoop or the like." Each of these particles has an "innate circular motion" and so tends to open out, being checked by the pressure of surrounding particles. Boyle went a step further when he took account of the effect of heat on gases: he added to the particles which were by nature springy, others that owed their elasticity to their motion. When heat was defined as a substance called caloric, this was held to be equivalent to "little springs bent between the molecules of air." Clearly the effort to translate theories into working models, if only in imagination, was a persistent element in the scientific thinking of this period. Boyle's analogies furnished a picture which aptly illustrated that relation between volume and pressure which is known as Boyle's Law.

Boyle was a great experimentalist and he realized that scientific knowledge must be limited to what is verifiable by experiment. But he was also capable of that wider outlook, which proceeds from scientific facts to a more comprehensive natural philosophy. He was aware of the peculiar problems which had come to light through the work of Gilbert and others in the field of magnetic attraction. These phenomena seemed to require some modification of the idea of matter and some explanation more refined than the mechanism of impact and impulsion upon which the Cartesians relied. Descartes based his rejection of the vacuum on the concept of a universal matter filling all space, capable by a vortex movement of causing the motions of the heavenly bodies. The purely speculative philosophers, like Henry More, exploited the incipient knowledge of magnetism in favour of a

universal spirit acting intelligently but mysteriously throughout the Universe. To a modern student of science this intermingling of physics and theology seems absurd and rather incredible. But the thinkers of the 17th century were not so highly specialized and, we may add, not so limited in their vision. We need to recollect that Boyle founded a lectureship to support the argument for the Divine government of the world, that the first Boyle lecturer (Dr. Bentley) relied on the Newtonian system to uphold his arguments, that Newton himself defined space as the "sensorium" of God, and that such mechanists as Descartes worked with the hypothesis of the "Concursus Dei," the unremitting co-operation of God. If the ideal of the new science was to reduce nature to numbers, its more competent exponents saw clearly that progress in that direction made necessary some independent agency which accounted for both the origin and the persistence of physical processes. Boyle's scientific habit of mind made him unwilling to accept the hypothesis of an "extended God" as suggested by Henry More: it made him equally suspicious that the principles of the mechanists were not fitted to deal with the complexities of a world in which chemistry and magnetism were offering intractable problems. Boyle had no doubts about the value of the mechanical method: in his experiments on the air he kept strictly within its limits. But beyond the immediate study of air by means of Torricellian tubes and air-pumps there lay the less manageable question of the kind of substance which pervaded the upper regions of the universe. According to the original Greek atomists there were only atoms and the void. According to the new science of the sixteenth century, the void was ruled out, partly because it involved transmission of force through empty space, partly because the active power attributed to the void had been proved erroneous. If there is no void anywhere, the universe must be filled with something and Descartes said that this was a "phlegmatic aether." By this hypothesis he provided a space-filling substance which he could regard as subject to mechanical laws of action. Since this aether was invented for a special purpose its utility was limited: its capacity for carrying along material bodies did not seem suited to explain the phenomena of magnetic attraction. Boyle attempted a compromise by suggesting that there were two kinds of matter, one like the "phlegmatic fluid" of Descartes, the other

described as consisting of "peculiar sorts of corpuscles that have yet no distinct name, which may discover peculiar faculties and ways of working when they meet with bodies of such a texture as disposes them to admit, or concur with, the efficacy of these unknown agents." This is obviously very tentative and indefinite, but it carries one step further the task of substituting for the discarded vacuum a suitable kind of matter. Boyle's success in what he called the rarefication of the air may be the reason for this revival of the concept of the aether, a word which had from the time of Aristotle been the symbol of the most subtle form of matter, an absolutely pure air. Newton's correspondence with Boyle shows the connection between these ideas and their relation to the persistent riddle of gravity. The idea that bodies move in order to reach their natural places had passed away with the advent of mechanistic theories: but the nature of gravity was left in the position of "a fact without a reason." Newton argued that a fluid medium did not satisfy the conditions and he specially stated that he did not favour "innate gravity." He was attracted by Boyle's suggestion. That he approached the problem of gravitation along this track is shown by the first outline of his hypothesis. He says: "It is to be supposed therein that there is an ethereal medium, much of the same constitution with air, but far rarer, subtler and more strongly elastic. Of the existence of this medium, the motion of a pendulum in a glass exhausted of air almost as quickly as in the open air is no inconsiderable argument. But it is not to be supposed that this medium is one uniform matter, but composed partly of the main phlegmatic body of aether; partly of other various ethereal spirits, much after the manner that air is compounded of the phlegmatic body of air intermixed with various vapours and exhalations. For the electric and magnetic effluvia, and the gravitating principle, seem to argue such variety." The gravitating principle is then explained as equivalent to the continual condensation of ether, so that it is perpetually descending and in its descent "it may bear down with it the bodies it pervades."

In Newton's work the final emphasis was laid on mathematical formulations which represented laws of nature. He expressed a dislike for hypotheses and was anxious not to commit himself to statements about the ultimate substance to which those laws might

refer. Consequently it would be an error of judgment to assign too much importance to the way in which Newton described the ether of space. But it is legitimate to quote his language because his words obviously reflect the mode of contemporary thought. The vortices of Descartes were so widely accepted that Newton was obliged to state his objections to that view of the structure of the Universe. To satisfy the demands of those who wanted to know what he thought about the constitution of the material world, Newton made such statements as the one we have quoted. This is clearly an outgrowth of the ideas which became dominant through the consideration of the air and its properties.

Torricelli's experiment was concerned with the physics of the air. Its influence in the history of science is most clearly seen in the development of hydrostatics, and it has a distinct part in the efforts to make the principle of gravity intelligible on mechanical principles. The seventeenth century has been called the century of genius. It was crowded with events which in quick succession secured the triumph of the new methods in the natural sciences. For obvious reasons the inventions and discoveries which affected traditional views about the heavens and celestial bodies were most conspicuous and attracted most attention. But the victory of the mechanistic and quantitative ideals was no less due to achievements in other fields about which public opinion was not so easily disturbed. Among these must be reckoned the study of the atmosphere. At a later date the subject develops into problems of chemical analysis with results of another kind, such as the discovery of oxygen. Such matters fall beyond the scope of our present topic. This may be concluded with the judgment that Torricelli's work takes its place as a significant contribution to the sum total of those investigations which by virtue of their originality in discarding theories consecrated by respect for authority and their fidelity to the experimental evidence, laid the foundations on which modern science has been built.

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THE APPLICATION OF THE BAROMETER IN PHYSICS AND CHEMISTRY

By JOHN SATTERLY

1. *The Measurement of Pressure in Dynes per Square Centimetre*

The expression for the pressure due to a liquid column is

$$p = g\rho h,$$

where g = the acceleration of gravity at the place of observation (cm. sec.$^{-2}$),

ρ = the density of the liquid (gm. per cm.^{3}),

h = the height of the liquid column (cm.).

The standard atmospheric pressure is defined as

$$p_{st} = g_{st}\, \rho_0\, h_0,$$

where ρ_0 and h_0 refer to the chosen liquid at 0°C. and g_{st} is the chosen standard value of g.

At one time standard g was taken as the value of g at sea-level in the latitude 45°. However g has never been measured at that position and interpolation was invoked to obtain this value. It was decided to accept the value $g = 980.665$ cm. sec.$^{-2}$ Since those days the geophysicists have been busy and now the value of g at sea-level in latitude 45° is taken by them as 980.621, recently corrected to 980.616 cm. sec^{-2}. And this despite the fact that Heyl with all the resources of the Bureau of Standards at Washington could only measure g there as 980.08 cm. sec.$^{-2}$, the third decimal place not being realizable. The workers in Barometry and its allied Thermometry decided, however, not to change and so we have two standard values of g.

The chosen liquid for the barometer being mercury and the chosen standard height of the mercury column being taken as 76.0000 cm., representing what is called the Standard Atmospheric Pressure, we have therefore

Standard Atmospheric Pressure for Barometry and Thermometry

$$= 980.665 \times 13.59504 \times 76.0000 \ldots\ldots$$

$$= 1.013246 \times 10^6 \text{ dynes cm.}^{-2}$$

The Standard Atmospheric Pressure for Geophysics is correspondingly

$$= 1.013195 \times 10^6 \text{ dynes cm.}^{-2}$$

These figures are taken from R. T. Birge's recent paper "A new table of values of the General Physical Constants" as of August 1941, printed in *Reviews of Modern Physics*, October 1941.

In any other place the height of the mercury column (at 0°C.), yielding the standard atmospheric pressure, must be computed from the local value of g. Thus in Toronto, where $g = 980.43$ cm. sec.$^{-2}$ the height of the standard barometer (at 0°C.) must be

$$76.000\ldots \times \frac{980.665}{980.43} = 76.018 \text{ cm.}$$

The *bar* is becoming a fashionable unit for the expression of pressure, especially with meteorologists. By definition

1 bar $= 10^6$ dynes cm.$^{-2}$ and 1 millibar is 1/1000 of this.

Therefore at the place where g has the standard value of 980.665 cm. sec.$^{-2}$ the pressure of 1 mm. of mercury is

$980.665 \times 13.59504 \times 0.1000 = 1.33326$ millibars.

There is, however, a practice of using the relation

1 mm. of mercury corresponds to 1.33326 mb.

as if it were universally true, whereas it is obvious that at the earth's poles where $g = 983.22$ cm. sec.$^{-2}$, 1 mm. of mercury corresponds to 1.3367 mb., and at the equator where $g = 978.04$ cm. sec.$^{-2}$ 1 mm. of mercury corresponds to 1.3229 mb., a 1% difference. It is a pleasure to see that now the most careful workers in researches dealing with the accurate measurement of pressures, if pressures are quoted in mm. of mercury, supply also the local value of g for turning these mm. of mercury into mm. at standard g or into millibars.*

2. *The Importance of Barometric Observations in Physics and Chemistry*

The chief importance lies in standardizing operations, thus:

(1) The boiling points of liquids to be quoted in the tables are the boiling points at the Standard Atmospheric Pressure. The boiling-point of a liquid changes rapidly with the pressure. Thus

*See, for example, *The Heat Capacity and Entropy, Heats of Fusion and Vaporization and the Vapour Pressures of Isopentane* by Schumann, Aston and Sagenkahn, in which the value of g at State College, Pennsylvania, is taken as 980.124 cm. sec.$^{-2}$ I.C.T., and thus their observed vapour pressures converted into Standard mm. of mercury.

the boiling point of water, defined as 100.0000°C. at the Standard Atmospheric Pressure, changes by 0.0367°C. per mm. change of pressure; and that of sulphur, whose standard boiling point is 444.60°, changes by 0.0909°C. per mm. change of pressure. These relations are good enough if the pressure does not deviate much from the standard. If the difference of pressure is large the following relations may be used:—

Temperature of equilibrium between liquid water and its vapour
$= 100.000 + 0.0367\ (p - 760) - 0.000023\ (p - 760)^2$,
and temperature of equilibrium between liquid sulphur and its vapour
$= 444.60 + 0.0909\ (p - 760) - 0.000048\ (p - 760)^2$;
where p is the pressure expressed in mm. of mercury at 0.0°C., at which the boiling is occurring. In Toronto we should, of course, use 760·18 instead of the 760 and similar precautions should be taken elsewhere.

In boiling point determinations the determinations of the pressure at which boiling occurs is therefore an important desideratum, a temperature measurement without a pressure measurement is a wasteful proceeding. Water and sulphur have been quoted above for the reason that their boiling points are accepted as primary standard points.

(2) In the measurement of mass, of density and of specific gravity the buoyant force of the air must always be considered if any reasonable accuracy is expected. Thus in measuring the mass of a body with an ordinary balance it is not good enough to say the mass of the body equals the mass of the balancing weights, for the buoyant force of the air will, in most cases, be different for the body and the "weights". We write

$$M = w_1 \frac{1 - a/b}{1 - a/D},$$

where M = true mass of the body,
w_1 = the apparent mass of the body = sum total of the the balancing weights
and a, b, D = the respective densities of the air, the material of the "weights" and the body weighed.
Also in the case of obtaining the density of a body by the use of

Archimedes' Principle, where the body in air is balanced by weight w_1 in air, and the body hanging in water is balanced by weight w_2 in air

$$D = \frac{w_1}{w_1 - w_2}\Delta - \frac{w_2}{w_1 - w_2}a,$$

where D, Δ, a = the respective densities of the body, water and air. Practically in all weighing operations a must be employed and, since the density of air varies with pressure, temperature and its relative humidity, one can see that many subsidiary operation smust be carried out if the density is required to an accuracy of, say, five significant figures.

(3) In the determination of the value of g by a pendulum where the standard formula

$$T = 2\pi\sqrt{\left(\frac{I}{gMh}\right)}$$

is used it must be realized that gM in the denominator represents the weight of the pendulum and this is lessened by the buoyant force of the air. The I of the numerator is increased by the presence of the air "carried" by the pendulum in its swing. So both numerator and denominator depend upon the density of the air which in turn depends upon the pressure, the temperature and the relative humidity of the air. The buoyant force correction for g is greater than is generally thought, being of the extent of $+0.15$ cm. sec.$^{-2}$ to the uncorrected value of g in the case of a brass pendulum.

These are just a few cases where a knowledge of the atmospheric pressure is necessary in physics and chemistry. In the case first quoted even small variations of pressure from standard conditions must be known.

3. *Errors in Barometry*

As quoted in the "Dictionary of Applied Physics", which is a quarry of information on this subject, the errors in barometry may be classified as follows:—

(1) An *imperfect vacuum* may exist above the mercury. This may be tested by raising or lowering the barometer tube in its cistern of mercury and noting whether the height of the mercury column varies as the space above the mercury is varied. The vapour

pressure of the mercury itself at 20°C. is of the order 0.001 mm. and would have to be considered if pressures were wanted to this order of accuracy.

(2) The *mercury may not be pure* (i.e. of density 13.59504 ± 0.00005 gm. cm.$^{-3}$ at atmospheric pressure. See Birge's paper). This may be checked by comparison with another barometer made with recently triply-distilled mercury. Mercury is also a mixture of several isotopes of different densities and this may cause a variation in its density unless ordinary mercury has always the same composition. Distillation may, however, change it.

(3) Errors in *cathetometry* and in the value of the *capillary depression*.

(*a*) The cathetometry depends upon the accuracy of the metal scale which stands alongside the barometer tube or the scale of the cathetometer itself if this is used. The scales are supposed to be correct at 0°C. and corrections should be made for their expansion with temperature (see later). The accuracy of the recording of the height of the mercury column depends on the verticality of the scale (and likewise the mercury tube) and the settings of the measuring instrument both at the level of the mercury in the cistern (the ivory point of the Fortin barometer) and at the top of the mercury column. The ordinary man is too apt to take for granted that everything about an instrument is correct. In many experiments where a manometer is in use the total pressure is obtained by adding the difference of levels in the (mercury) manometer to the barometric height. This necessitates four separate observations, two each for the top and the bottom of the mercury columns in barometer and manometer. Four observations make for decrease of accuracy. In some cases, as in the apparatus designed by Chappuis (and also by Travers)* for the measurement of temperatures by gas expansions the barometer is made an integral part of the apparatus. By the simple device of placing the bottom of the barometer tube in the open leg of the manometer two readings are done away with, and by the further device of bending the barometer tube so that the upper portion of the barometer is in the same vertical line as the

*See any standard textbook of Heat or the "Dictionary of Applied Physics".

apparatus end of the manometer the accuracy of the measurement of total pressure is greatly enhanced.

(*b*) *The Capillary Depression.* There is a difference of pressure between the fluids on the two sides of a curved surface, the fluid on the concave side being at the greater pressure. This is a consequence of molecular forces and the pressure difference is given by

$$p = \gamma(1/R_1 + 1/R_2),$$

where γ = the surface tension of the surface film or layer and R_1, R_2 are the principal radii of curvature of the surface at the point selected. For a spherical surface of radius R the equation gives $p = 2\gamma/R$. For a mercury surface γ is about 460 to 490 dynes per cm. and if R were as small as 1 mm. the pressure difference would be $(2 \times 475)/0.1 = 9500$ dynes cm.$^{-2}$ or 9.5 millibars or equal to that of 12.7 mm. of mercury.

Hence if one sets up a barometer in a narrow tube the mercury surface, or meniscus, as it is called, is very curved and the pressure immediately below the meniscus is greater than that of the vacuum by a finite quantity. Hence a barometric column in a narrow tube stands at a lower height than in a wide tube. The difference is called the *capillary depression.* Hence in all but wide-tube barometers a positive correction must be made to the height of the mercury column in order to find the true height of the barometer. The correction depends on the surface tension of the mercury and the curvature of the meniscus. The surface tension in turn depends on the purity of the mercury and the temperature. It is hard to measure the curvature of the meniscus and in practice the correction is expressed as a function of the diameter of the tube and the height of the meniscus, the height being the difference between the level of the horizontal plane at the top of the meniscus and the horizontal plane through the points of contact of the periphery of the mercury surface with the wall of the tube.

Books of tables give the value of the capillary correction but there is some doubt as to the right value (which depends on the surface tension of the mercury and the shape of the meniscus). An extract is given here where the third column gives the correction tabulated in Kaye and Laby's "Tables" and the "Handbook of Chemistry and Physics" (same source) and the fourth column gives the correction quoted in the "Dictionary of Applied Physics."

CORRECTION FOR CAPILLARITY

For		To be added	
Diameter of Tube	Height of Meniscus	K. and L.	D.A.P.
25 mm.	2.0 mm.		.030 mm.
10 "	1.2 "	.25 mm.	.35 "
10 "	1.0 "	.10 "	.30 "
10 "	0.8 "	.15 "	.24 "
5 "	1.2 "	1.45 "	....
5 "	1.0 "	1.19 "	....
5 "	0.8 "	.80 "	....
1 "	0.2 "	....	9. "

The magnitude of the correction shows that careful measurements of diameter and height are necessary if the tube is narrow. The best remedy is to use wide tubing. The standard barometer in Paris has a tube of diameter 3.6 cm. Here the correction is negligible. The chief barometer in the Physics Building in the University of Toronto has a bore of about 15 mm. and with this if the height of the meniscus is 0.7 mm. the correction is of order 0.02 mm. As this barometer can, however, be only read consistently to an accuracy of 0.1 mm. the correction is negligible.

The shape of the meniscus is variable, depending on whether the mercury is rising or falling. One usually taps the barometer to get the meniscus into a steady state and then hopes for the best.

The readings of the best Fortin type of barometer can be made to 0.02 mm. and it is desirable for meteorological purposes to go to 0.01 mm. in order to detect the trend of the variation of the atmospheric pressure but this will prove very difficult.

4. *The Correction for Temperature*

Assuming that the mercury and the scale of the barometer are uniformly at t°C. and that the scale is correct at 0°C., the "Reduced to Zero" height of the barometer

$$= (\text{Observed Height}) \times \frac{1+lt}{1+ct},$$

where l = coefficient of linear expansion of the material of the scale,
c = coefficient of volume expansion of the mercury.

If an accuracy to only 0.1 mm. is required this formula will lead to

"Reduced to zero" ht. = Observed ht. − Observed ht. $(c-l)t$.

Thus if the scale is on brass, the temperature is 20°C. and the Observed height = 757.8 mm., the "Reduced to Zero" height

$$= 757.8 - 757.8 \times (0.000182 - 0.000019 \times 20,$$
$$= 757.8 - 757.8 \times 0.000163 \times 20,$$
$$= 757.8 - 2.5 = 755.3 \text{ mm.}$$

If an accuracy of 0.01 is required the expression

$$\text{"Reduced to zero" ht.} = \text{Observed ht.} - \text{Observed ht.} \times \frac{(c-l)t}{1+ct}$$

should be employed. Some barometric scales are engraved to give correct millimetres at 20°C. This would make the temperature correction larger. Obviously the observer must enlighten himself by making his own enquiries about the scale. It should, however, be noted that to get an accuracy of 0.02 mm. the temperature of the scale and mercury should be read to 0.2°C., and it is not an easy thing to ensure a uniform temperature over the whole of the length of the barometer to this degree. The thermometer indicating the temperature of the barometer should preferably dip into a tube of mercury placed alongside the barometer so that its temperature may change at the same rate as that of the mercury column. An exposed thermometer will suffer greater variations of temperature. It is therefore advisable that an observer setting out to read the barometer should read the thermometer first, for this instrument will be the first to change because of the nearness of the observer.

5. *Change of Altitude*

In the laboratory the barometer may not be on the same floor as the experimenter's apparatus. A correction for change of level is required. Even a change of only 1.00 metre of level at a temperature t and pressure p mm. of mercury will make a change of pressure equal to

$$1000 \times \left(.001293 \times \frac{273}{273+t} \times \frac{p}{760} \right) / 13.6,$$

which at $t = 0$°C. and $p = 760$ mm. reduces to

$$\frac{1000 \times .001293}{13.6} = \frac{1.29}{13.6} = .09 \text{ mm. of mercury.}$$

An ascent of 1 metre therefore in general lowers the atmospheric pressure by about one-tenth of a mm. of mercury.

6. *Numerical Example*

We shall conclude by quoting an example of the use of the barometer for testing the accuracy of a thermometer in the neighbourhood of the 100-degree mark. Place—the Physics Building, University of Toronto. The barometer is on the top floor. The thermometer is being tested in Room 43 on the main floor, the method used being a determination of the temperature of the steam from water boiling in a large metal hypsometer. The steam pressure to which the thermometer is exposed is obviously a little greater than the atmospheric pressure at the place or the steam could not emerge from the hypsometer. A little U-tube manometer containing water measures this difference of pressure. The observations are:—

Barometer on top floor. Temperature 21°C. Observed Height 749.2 mm.

Difference of altitude of the cistern of the barometer and the bulb of the thermometer = 9.5 metres. Reading of the thermometer = 99.07°C. The water levels in the manometer attached to the hypsometer differ by $1\frac{1}{2}$ mm. Set out the corrections thus:

Observed height on the top floor.....	749.2 mm.
Tube 15 mm. in diam., capillary correction.	.0
Correction to 0°C.....	−2.5
"Reduced to Zero" height on the top floor.	746.7
Correction for 9.5 metres change of level..	+ .8
∴ "Reduced to Zero" height on the main floor	747.5
Correction for excess pressure within hypsometer.....	+ .1
Pressure of the steam around thermometer.	747.6
Reduce to standard gravity.....	− .2
	747.4 standard mm.

Reference to boiling point tables yields the following:

p	Boiling point of water
760.00 mm.	100.000°C.
748.0 "	99.56 "
747.0 "	99.52 "

By interpolation the boiling point at 747.4 mm. is 99.54°C., whence we see that the thermometer reads 0.47° low, or the correction in the neighbourhood of 100°C. is +0.47°C.

Apparatus used in the Lecture

The lecture was illustrated by the presence of the following apparatus on the lecture table: A Fortin (cistern) barometer, a Siphon barometer with sliding scale, a Boys' capillary tube barometer, a large sensitive aneroid barometer (parts visible), a pocket aneroid with rotating elevation scale, a Negretti & Zambra recording barograph, and a hypsometer in use for testing the correction to a thermometer at the steam point (see above).

Time failed at the lecture to permit of the discussion of the use to the Physicist and Chemist of high and low pressure gauges, vacuum gauges and manometers in general. References were made to the textbooks on such gauges, to Bridgman's work at Harvard, and to the "Dictionary of Applied Physics."

University of Toronto,
October 28, 1943.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

The Carnegie Telescope at Lick

In Lick Observatory Bulletin, No. 512, Miss Julie Vinter Hansen publishes twenty-four sets of observations of accurate positions of the asteroid Eros. These positions will be of use in keeping the orbit of this important asteroid up to date. The observations were made during the autumn of 1942 with the fine new Carnegie Astrographic Telescope of the Lick Observatory. They represent the first systematic research programme carried through with this telescope. It is pleasing to learn that this telescope functions excellently. For these exposures, up to four minutes' duration, the drive was sufficiently accurate so that no guiding was necessary even for this position work.

It is interesting to note that Dr. Vinter Hansen, who for years was on the staff of the Copenhagen Observatory in Denmark, was led to undertake this work by the receipt of an ephermeris computed by Dr. Stracke of Berlin and forwarded from Germany to America.

Dimout at Los Angeles

Each year astronomers look forward to the survey of the year's work at Mount Wilson as written by Dr. Adams, the Director. This year, despite some reduction in the staff due to war activities, a remarkably large and diversified programme of research has again been summarized. The solar observations and the work of both the 60-inch and 100-inch telescopes have been carried through without interruption.

Without here repeating Dr. Adams' summary of the research carried on, attention is called to one advantage of war conditions. Due to the dimout regulations in and about Los Angeles and Pasadena, the southern and western regions of the Mount Wilson sky have been appreciably darkened by elimination of the scattered light from the city. This darkening has allowed a doubling of exposure time on faint objects without increase of sky-fog. As a result good exposures have been possible on very faint variable stars and extragalactic nebulae. F. S. H.

Astronomical Discoveries in 1943

Below are listed what *Science Service* considers to be very important additions to our astronomical knowledge during the year 1943.

Evidence of gold in the sun was obtained by comparative study of gold spectrum lines and the solar spectrum.

Thorium, rare radioactive element, was discovered in the sun by detecting lines in the solar spectrum that matched lines of thorium produced in the laboratory.

The sun entered a new 11 1/3-year sun-spot cycle with the first new spot group appearing as expected well away from the sun's equator and one of the last spot groups of the old cycle still visible close to the equator.

New comets discovered were: Diamaca, Oterma III.

Periodic comets rediscovered were: Comas-Sola, last seen in 1935; Comet d'Arrest, last seen in 1923.

A nova or exploding star was discovered in the constellation Aquila.

Nova Puppis, discovered in November 1942, faded below naked-eye visibility.

The shell of the star 48 Librae was found to be composed of separately rotating hot layers.

In February, Comet Whipple II increased its brightness by nearly two magnitudes in a sudden and unexplained manner.

Nitro-hydrogen molecules made up of more than two atoms and hitherto unidentified in comets were found by spectrogram measurements to be numerous in the heads of Comet Cunningham and Comet Whipple II.

One star of the binary Beta Cephei was found to be the brighter member in a double star with a period of 50 years.

C. A. C.

MEETINGS OF THE SOCIETY

AT TORONTO

May 24, 1943.—The Society met at 8.15 p.m. in the McLennan Laboratory, University of Toronto, to commemorate the Quadricentennial of the death of Nicholas Copernicus. Miss R. J. Northcott presided.

An address on "The Work of Copernicus" was given by Dr. Frank S. Hogg. "Copernicus holds a unique place in the history of astronomy, and modern astronomy may be said to have its beginning with the publication of the Polish scientist's great work *De Revolutionibus Orbium Coelestium* in 1543," Dr. Hogg said. The meeting was being held on the exact 400th anniversary of Copernicus's death at 70 years of age on May 24, 1543, after the first copy of his book had been put into his hands as he lay on his deathbed.

"Very little is known of Copernicus's family—a fact that has caused Poles and Germans ever since to argue about his nationality. He was born in Torun or Thorn in 1473 in the territory then known as Polish Prussia. History records that his sympathies were evidently Polish rather than German.

"His early education was supervised by his uncle, Lucas Watzelrod, Bishop of Ermland (Varmia), and Copernicus studied to be a churchman and physician. But while a student at the University of Krakow he became interested in astronomy and mathematics. Later he studied in Italy at Bologna and Padua, and became a lecturer in mathematics at the University of Rome. His first recorded astronomical observation, the occultation of Aldebaran, was made in Italy in 1497. Returning to Poland, Copernicus became a canon and adviser to his uncle, the bishop, but he continued to carry on his studies and observations in astronomy. He also took time to lead his countrymen in the wars against the Teutonic Knights, and held the rank of commander of militia.

"Copernicus was called upon by King Sigismund to investigate the currency of Poland which had got into a bad state. His report put 'phoney' money alongside high mortality, internal discord and poor crops as the chief ills that can befall a nation. The coinage, he found, was only half gold. 'You cannot debase your coinage and expect it to yield full credit,' Copernicus reported to the king. The principle he stated then—'when bad money is in circulation with the good, the bad regulates the value of the whole and drives out the good'—is familiar to modern economists as Gresham's Law, having been attributed to Sir Thomas Gresham by a later historian who did not know it originated with Copernicus.

"Copernicus's contributions to astronomy were almost the first change in ideas about the universe since the time of Ptolemy, some 1500 years before. During all that period the geocentric hypothesis had been commonly accepted without question. Ptolemy had adopted the method of epicycles to explain the planetary motions and more and more epicycles had been added to explain residual errors in the orbits until 47 were in use. Copernicus, in presenting

his heliocentric hypothesis, for the first time offered a concrete idea in direct opposition to the Ptolemaic.

"Following up on Copernicus's hypothesis, Tycho Brahe built apparatus with which to test it and made more accurate observations. Kepler further improved on the observations and brought forth his laws of planetary motion, and Newton provided a quantitative explanation for them. All these advances arose from the attempt of the scientists who followed him to find that Copernicus's ideas were right," Dr. Hogg said.

An observational period to follow the meeting was cancelled because of rain, but members remained for some time after formal adjournment at 9.30 p.m. to discuss matters arising from Dr. Hogg's address and other matters of astronomical interest.

FREDERIC L. TROYER, *Recorder.*

Outdoor Summer Meetings, Toronto, 1943

Four summer observational meetings on the University of Toronto campus were scheduled:

Friday, June 11, 9.15 p.m.
Friday, July 9, 9.15 p.m.
Monday, August 9, 9.00 p.m.
Monday, September 6, 8.30 p.m.

Only the first two were held, rain causing cancellation of the August and September meetings. The June and July meetings provided opportunity for many members as well as visitors to observe the Moon, Venus and double stars through several telescopes. The instruments in use included the Society's four-inch Cooke refractor; the University of Toronto four-inch Zeiss refractor, and Mr. H. V. Wilkin's six-inch reflector. At the July meeting Mr. T. E. Cannon and Mr. K. Dalzell also brought their own instruments. An estimated 200 to 300 persons were present each evening.

The meetings were in charge of a committee, appointed by Council of Toronto Centre, comprising: Dr. D. W. Best, Miss Ruth J. Northcott, Frederic L. Troyer C. A. Crook and W. R. Sherrick.

FREDERIC L. TROYER, *Recorder.*

AT WINNIPEG

November 11, 1943.—The meeting was held in the University of Manitoba at 8.15 p.m. The president, Mr. V. C. Jones, introduced the speaker, Mr. D. C. Archibald, Western Superintendent, Dominion Government Department of Transport.

Mr. Archibald who interrupted his western inspection trip at Winnipeg to give an address to the Centre chose as his subject, "Airways Weather Forecasting."

He began by saying that forecasting to-day dealt with the weather in the

20,000 feet above the earth's surface. To make this possible reports from meteorological stations over North America and the surrounding oceans are received several times a day. These reports are sent by teletype in code over the C.P.R. west and over the C.N.R. east of Winnipeg. The radio is used in our northland and is handled by the Department of Transport. The reports give: wind direction and velocity; clouds—amount, kind and height; temperature; barometer reading; humidity; precipitation and visibility. A sample report was shown and each item explained.

From these various facts the weather forecaster can tell of the presence of warm air masses and cold air masses. These "fronts" are very important in our latitudes. If they are flowing side by side the warm air makes a bulge and cold air flows round it. This is the birth of a storm. If both fronts try to move over the same area the cold air acts as a wedge and pushes under the warm air. This gives rise to thunderstorms at the "front" and all-day rains farther back. When the warm air mass is lifted completely off the earth it is said to be occluded and gives great precipitation.

The meteorologists of Norway were the first to understand how these warm and cold fronts mould and affect the weather—possibly because the Norwegian fishing fleets needed to be able to foretell the weather.

The most easily recognized factors which change as a cold front approaches are: the direction of the wind veers, the velocity of the wind is jumpy and high, the atmospheric pressure falls temporarily and then goes up, the temperature falls, the humidity is less. These changes often happen suddenly. One day last winter a cold front advanced from Edmonton to Winnipeg in six hours.

The paths of the passing fronts for many years have been plotted. They are fairly stationary for each season but vary greatly from season to season. Winter storms sometimes die out but sometimes they become rejuvenated.

The future will probably demand longer time forecasting to allow bombers to cross the ocean. Even if the flying is done at a height of 20,000 to 25,000 feet to avoid storms, the plane has to come down through the storms in the lower atmosphere to land.

"Hitler weather," the belief that Germany has had a long-range view of the future weather, is a myth. By Hitler's own admission the Russian reverses during the first winter were due to unexpected severe weather. Germany seems to be making desperate attempts to establish observing stations far out in the Atlantic.

Discussion on many related questions closed this most interesting lecture.

OLIVE A. ARMSTRONG.

December 9, 1943.—The regular meeting of the Winnipeg Centre was held in Theatre F, University of Manitoba. Mr. L. W. Koser took the chair as the president, Mr. V. C. Jones, gave the address. Slides, some of which were loaned by the David Dunlap Observatory, added interest to a most lucid lecture.

Mr. Jones began by saying he had gathered together some general ideas given to us by astronomers and had correlated them.

The number of stars is fairly constant per unit of space. For a sphere of radius 10 light-years the number of stars is 10 and for the galaxy, of which our solar system is a part, and whose radius is 5000 light-years the number of stars is 1,250,000,000.

Besides our own Milky Way, two other galaxies are visible in the northern hemisphere—the Great Nebula in Andromeda and another, M33, in Triangulum. In the southern hemisphere are to be seen the Great and Lesser Magellanic Clouds. With large telescopes other nebulae are found in every direction except through our Milky Way.

The proof that spiral nebulae are galaxies was given under seven headings, each of which was fully explained: (1) Lenticular shape, (2) Star Clouds, (3) Star Clusters, (4) Giant Stars—blue, (5) Novae, (6) Rotation, (7) Cepheids.

When the distances are too great to find cepheids, less exact means must be found. Among these are: (1) Distance of the sun, (2) Parallax of stars, (3) Stellar motions, (4) Spectrographic parallalaxes, (5) Cepheids, (6) Brightest stars in nebula, (7) Luminosities of nebula, (8) Brightest nebula of clusters.

Nebulae change in well known progression, dissipating their nuclei as they evolve. One of the principal purposes in building the 200-inch telescope at Mt. Palomar is to find if there is a limit to nebulae. Spiral nebulae cannot be seen everywhere through the Milky Way because of obscurity. At the edge and at the galactic pole there are about 2400 in a square degree. Thus in all space there is a total of about 100 million galaxies and 5 quintrillion stars.

The motion of stars was then discussed. In our galaxy it has been proved that stars nearest the centre travel fastest. The time for our sun to complete one journey in its orbit requires about 200 million years.

Our sun loses in light and heat more than four million tons each second. As the sun is smaller each succeeding year its gravity is less and we must be getting farther and farther away. This loss due to radiation applies to every star in a nebula and accounts for the gradual spreading out of the nebula in its evolution.

The shift to the red was likened to an engine whistle that lowers in pitch as it passes the hearer. This is because the sound waves are crowded together ahead of the moving whistle and are stretched out back of it. Light from a moving object has a similar result. If a star is going away at high speed it stretches out the light-waves and they appear longer. This causes the red shift of the lines of the spectrum. All nebulae have a definite red shift. The more distant the nebula the greater the red shift and therefore the higher the speed. This increase of speed is found to be 100 miles per sec. for every million light-years of distance. The greatest shift so far measured is for a nebula at the extreme limit of the observable region (500,000 l.-y.) and the speed indicated was 26,000 mi. per sec. or one-seventh the speed of light. This speed reduces the brightness by one-seventh, giving the astronomers another

serious problem to contend with. Knowing the speed and distance, astronomers have calculated when the original explosion was "ignited." These calculations vary from one to 1.8 billion years ago.

The uses of astronomy were briefly reviewed. The striving for knowledge about the stars has resulted in the world of science to-day. We use stars for accurately measuring time, land-surveying and navigating the sea and air. A possible future development that may come from the study of astronomy is to release the illimitable store of energy now locked up within the atom. The most useful knowledge that we owe to astronomers is that which is not directly applicable.

Discussion closed a most interesting lecture.

OLIVE A. ARMSTRONG.

AT VICTORIA

October 13, 1943.—The meeting opened at 8 p.m. with Mr. O. M. Prentice, the president, in the chair. The minutes of the last meeting were read and adopted. Miss Langworth spoke of two new books which had been added to the library. Mr. R. Peters gave a short talk on current phenomena. He commented on the harvest and the hunter's moon and the brightness of Venus which now appears early in the morning, of magnitude –4.5. He gave a few definitions of astronomical terms, great circle, altitude and azimuth.

Lt. Comdr. C. A. McDonald, a charter member and past president of the Vancouver Centre was introduced by Mr. Prentice. His talk was entitled "Straight Lines and Circles in Navigation". By means of simple diagrams he gave explanations of practical problems in everyday piloting. He commenced his lecture by narrating the story of the cocoanut shell in which two holes were bored and the shell filled with water to the lower one, the angle formed between the line between the two holes and the surface of the water being the elevation of the sun at their destination on a particular day. This crude instrument was in effect the first bubble sextant. He also described the beginnings of the magnetic compass. In travelling between China and Japan, a lodestone was suspended from a piece of string and as long as this was at right angles to the path they were to travel, they would be going east or west. By putting a piece of paper below the suspended stone and sailing along a path so that the lodestone lay parallel to a certain mark on the paper the first compass was made.

He explained how distance of a height of land or lighthouse can be calculated from a ship if one knows the curvature of the earth, elevation of the height of land and the height of eye on ship. By drawings he showed the meanings of course line and position line and how these are altered to compensate for a current or tide. He emphasized the importance of observation and recording every observation. The Encyclopedia Britannica is the best source book for the beginner in navigation.

Lieut. McDonald showed how a navigator can calculate the danger angle in order to pass between two rocks safely. Soundings or charted depths of ocean

also help to give positions. The echo method is also used. This method requires much experience, however. He concluded with some explanations of celestial navigation. The angle of elevation of N star is the latitude of the observer. By finding the zenith distance of a known star or sun, since the declination of the star is known, latitude can be calculated. Finding longitude can also be a straight line problem by observing the object on the prime vertical but it is in general impractical.

He finally described a new and simple method of obtaining latitude and longitude. Treat the ship or plane as a star and, using a 3-foot globe marked with right ascension and declination circles, find the point of intersection of altitude circles of two known stars on the globe. This is your position and by noting the declination marked on the globe at this point you can obtain directly your latitude. The right ascension is also marked and by comparing with the chronometer which gives G.M.T. the longitude is obtained. Lieut. McDonald stated that this method should come into wide use.

November 10, 1943.—The meeting was called to order at 8.15 p.m. by the president, Mr. O. M. Prentice.

Dr. Andrew McKellar of the Dominion Astrophysical Observatory was introduced by the president and spoke on "Recent Improvements in Telescopes and Their Auxiliaries". He explained that by "recent" he meant in the last 10 years. First Dr. McKellar described the process of aluminizing the 72-inch mirror of the Dominion Astrophysical Observatory. Slides were shown illustrating the vacuum chamber, in which the metal was evaporated from tungsten coils, thus coating the mirror with aluminum which gives a more durable coat than silver and one which is better for the ultraviolet region. This process was developed by John Strong.

Then Dr. McKellar described the coating of lenses and prisms with non-reflecting layers of fluoride by an evaporation process or a chemical one. Thus instead of only 90% of light being transmitted as from each ordinary glass surface, 99% of light is transmitted. The process is a result of destructive interference.

Finally Dr. McKellar spoke of the Schmidt telescope which was developed in 1932. This device was used to improve the field of good definition on a photographic plate eliminating the effect of coma. A correcting plate is used to bend the light from the spherical mirror so the outside rays come to a focus at the same point as the inside rays. Very great speed can thus be obtained, and images of objects several degrees off the main axis are just as good as the main image. But film must be used instead of photographic plates as the focal surface is spherical.

December 1943.—The meeting took the form of the Annual Dinner held at the Y.W.C.A. at 6.30 p.m. Sixty-two members and friends were present. An enjoyable musical program was provided by Mr. and Mrs. Pierre Timp, Mr. J. Burchet and Mrs. C. S. Beals.

After the dinner, the gathering stood in silent tribute to Mr. Dean and

Mrs. Crouch. A short business meeting was held. The minutes of the December meeting of 1942 were read and the Secretary's and Treasurer's and librarian's reports were read. Mr. Shaw gave a hearty vote of thanks to the musicians.

Mr. Sutherland read one of his own poems "The Milky Way" which was much appreciated.

The president, Mr. O. M. Prentice, gave a short report commenting on the success of the summer course and the increase in membership. He thanked the other members of the Council and those who had assisted in the past year by their lectures to the Society.

The annual election of officers was conducted. The following were elected to offices for 1943-44:—Mr. R. Peters, honorary president; Mr. O. M. Prentice, president; Dr. A. McKellar, first vice-president; Dr. K. O. Wright, second vice-president; Mrs. M. V. Yarwood, secretary-treasurer; Miss Y. Langworth, librarian; Mrs. W. Stilwell, recorder; Mr. Hobday, in charge of telescope making section; Council—Dr. W. P. Walker, J. Moulson, W. Stilwell, H. D. Day, M. Trueman, Dr. J. Stevenson.

Dr. McKellar introduced the guest speaker, Mr. Sandham Graves, editor of the *Victoria Daily Colonist*. His subject was "The Place of the Observatory in the Community". Mr. Graves began his lecture by stating that astronomy was essentially a study of the mind of man and a science of pure inquiry. He traced the development of this pure science from its beginning, mentioning Sargon who was prominent in this science in 3800 B.C. when it was mainly a worship of the stars. He traced it through the centuries, from the Egyptians of 3000 years ago and the Chaldeans who offered their sacrifices when the north star shone through a slit in their temple wall. He mentioned some of the hundred men from Sargon to Einstein who had contributed to the progress of the science.

He gave an idea of the artist's concept of astronomy and concluded by stating how the observatory had added to the sum total of knowledge and how the man in the street usually did not understand or appreciate the great contribution an observatory makes to the world.

E. STILWELL, *Recorder*.

AT EDMONTON

October 14, 1943.—The president called the meeting to order at 8.25 p.m. Dr. Campbell reported on the moon model, which will be mounted, with its key, as soon as the latter can be framed.

The president gave a short account of the official opening of the new Observatory last May, referring to the report in the JOURNAL.

On motion the secretary was instructed to cast a ballot electing the following candidates:

Miss Josephine Boyar, 11733-92 St.
Albert J. Moss, 10847-94 St.
Fred A. Sawchuk, 9636-109 A Ave.
Thomas Roycroft.

On the motion of Mr. Stockwell and Miss Malanchuk the secretary was instructed to arrange the annual dinner meeting at the Corona Hotel on December 9.

The HANDBOOK talk was given by Mr. Wates. The crescent of Venus is bright and prominent in the morning sky. A very full and clear explanation of harvest and hunter's moons was given, with the aid of a clever series of diagrams.

Dr. Gowan showed a slide of the constellation Capricornus.

The main paper, on "Latitude and Longitude", was given by Mr. Zinkan. Both these terms have terrestrial and celestial applications. The many things necessary to determinations by observation were described. These include: knowledge of astronomy, instruments for the measurement of angles, the notation of numbers, printing, astronomical tables, accurate timepieces, glass for lenses and mirrors in instruments. The final precision in latitude determined on land is to the nearest couple of feet.

The meeting was then thrown open for discussion and questions. The height of the tide depends on the time of year, and perhaps on the distance of the moon. Greenwich is the prime meridian now used by all countries, but there have been others in the past. The earliest maps were of the Mediterranean area only, and the term latitude started as describing the short way across these maps, longitude the long way.

E. H. GOWAN, *Honorary Secretary.*

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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
1890-1943

The Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal and Quebec, P.Q.; Ottawa, Toronto, Hamilton and London, Ontario.; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as about 800 members of these Canadian Centres, there are over 200 members not attached to any Centre, mostly resident in other nations, while some 300 additional institutions or persons are on the regular mailing list for our publications.

The Society publishes a monthly JOURNAL containing about 500 pages and a yearly OBSERVER'S HANDBOOK of 80 pages. Single copies of the JOURNAL or HANDBOOK are 25 cents, postpaid. In quantities of 10 or more copies, the price is 20 cents a copy.

Membership is open to anyone interested in astronomy. Annual dues, $2.00; life membership, $25.00. Publications are sent free to all members or may be subscribed for separately. Applications for membership or publications may be made to the General Secretary, 198 College St., Toronto.

The Society has for Sale:

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(Continued from previous page)

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Conseil—ABBE R. BENOIT; JEAN-CHARLES MAGNAN; LIONEL GALLICHAN; ALBERIC BOIVIN; HENRI-PAUL KOENIG